

LETTER TO THE EDITOR

Strange form factors of the proton in a two-component model

R. Bijker \ddagger

Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, AP 70-543, 04510 México, D.F., México

Abstract. The strange form factors of the nucleon are studied in a two-component model consisting of a three-quark intrinsic structure surrounded by a meson cloud. A comparison with the available experimental world data from the SAMPLE, PVA4, HAPPEX and G0 collaborations shows a good overall agreement. The strange magnetic moment is found to be positive $\mu_s = 0.315 \mu_N$.

PACS numbers: 13.40.Gp, 12.40.Vv, 14.20.Dh, 24.85.+p, 13.40.Em

Submitted to: *J. Phys. G: Nucl. Phys.*

\ddagger E-mail: bijker@nucleares.unam.mx

1. Introduction

Electromagnetic and weak form factors are key ingredients to the understanding of the internal structure of the nucleon, since they contain the information about the distributions of electric charge and magnetization. Deep-inelastic scattering experiments have demonstrated that the structure of the proton cannot be described by its uud valence structure alone: the valence quarks carry less than 50 % of the proton momentum and less than 30 % of the proton spin. Especially, the contribution of strange quarks to the nucleon structure is of interest because it is exclusively part of the quark-antiquark sea. In recent experiments, parity-violating elastic electron-proton scattering has been used to probe the contribution of strange quarks to the structure of the nucleon. The strange quark content of the form factors is determined assuming charge symmetry and combining parity-violating asymmetries with measurements of the electric and magnetic form factors of the proton and neutron [1].

The first experimental results indicate that the strangeness content of both the magnetic moment and the radius of the proton is positive [2], an unexpected and surprising finding, since a majority of theoretical studies favors a negative value for both quantities [3]. The aim of this Letter is to present a study of strange form factors in a two-component model of the nucleon [4, 5] and to analyze the available experimental data.

2. Two-component model

The momentum dependence of the current matrix elements is contained in the Dirac and Pauli form factors, $F_1(Q^2)$ and $F_2(Q^2)$, respectively. The electric and magnetic (Sachs) form factors are obtained from F_1 and F_2 by the relations $G_E = F_1 - \tau F_2$ and $G_M = F_1 + F_2$ with $\tau = Q^2/4M_N^2$. The Dirac and Pauli form factors are parametrized according to a two-component model of the nucleon [5] in which the external photon couples both to an intrinsic three-quark structure described by the form factor $g(Q^2)$ and to a meson cloud through the intermediate vector mesons ρ , ω and ϕ . In the original version of the two-component model [4], the Dirac form factor was attributed to both the intrinsic structure and the meson cloud, and the Pauli form factor entirely to the meson cloud. In a modified version [5], it was shown that the addition of an intrinsic part to the isovector Pauli form factor as suggested by studies of relativistic constituent quark models in the light-front approach [6], improves the results for the electromagnetic form factors of the neutron considerably.

The isoscalar and isovector form factors correspond to the currents $J_\mu^{I=0} = (\bar{u}\gamma_\mu u + \bar{d}\gamma_\mu d - 2\bar{s}\gamma_\mu s)/6$ and $J_\mu^{I=1} = (\bar{u}\gamma_\mu u - \bar{d}\gamma_\mu d)/2$, respectively. The isoscalar Dirac and Pauli form factors contain the couplings to the ω and ϕ mesons

$$F_1^{I=0}(Q^2) = \frac{1}{2}g(Q^2) \left[1 - \beta_\omega - \beta_\phi + \beta_\omega \frac{m_\omega^2}{m_\omega^2 + Q^2} + \beta_\phi \frac{m_\phi^2}{m_\phi^2 + Q^2} \right],$$

$$F_2^{I=0}(Q^2) = \frac{1}{2}g(Q^2) \left[\alpha_\omega \frac{m_\omega^2}{m_\omega^2 + Q^2} + \alpha_\phi \frac{m_\phi^2}{m_\phi^2 + Q^2} \right], \quad (1)$$

and the isovector ones the coupling to the ρ meson [5]

$$\begin{aligned} F_1^{I=1}(Q^2) &= \frac{1}{2}g(Q^2) \left[1 - \beta_\rho + \beta_\rho \frac{m_\rho^2}{m_\rho^2 + Q^2} \right], \\ F_2^{I=1}(Q^2) &= \frac{1}{2}g(Q^2) \left[\frac{\mu_p - \mu_n - 1 - \alpha_\rho}{1 + \gamma Q^2} + \alpha_\rho \frac{m_\rho^2}{m_\rho^2 + Q^2} \right]. \end{aligned} \quad (2)$$

This parametrization ensures that the three-quark contribution to the anomalous magnetic moment is purely isovector, as given by $SU(6)$. The intrinsic form factor is a dipole $g(Q^2) = (1 + \gamma Q^2)^{-2}$ which coincides with the form used in an algebraic treatment of the intrinsic three-quark structure [7]. The large width of the ρ meson which is crucial for the small Q^2 behavior of the form factors, is taken into account in the same way as in [4, 5]. For small values of Q^2 the form factors are dominated by the meson dynamics, whereas for large values they satisfy the asymptotic behavior of p-QCD, $F_1 \sim 1/Q^4$ and $F_2 \sim 1/Q^6$ [8].

3. Strange form factors

The strange quark content of the nucleon form factors arises through the coupling of the strange current $J_\mu^s = \bar{s}\gamma_\mu s$ to the intermediate vector mesons ω and ϕ . Note that here the convention of Jaffe [9] for the strangeness current has been adopted. The wave functions of the ω and ϕ mesons are given by

$$\begin{aligned} |\omega\rangle &= \cos\epsilon |\omega_0\rangle - \sin\epsilon |\phi_0\rangle, \\ |\phi\rangle &= \sin\epsilon |\omega_0\rangle + \cos\epsilon |\phi_0\rangle, \end{aligned} \quad (3)$$

where the mixing angle ϵ represents the deviation from the ideally mixed states $|\omega_0\rangle = (u\bar{u} + d\bar{d})/\sqrt{2}$ and $|\phi_0\rangle = s\bar{s}$. Under the assumption that the strange form factors have the same form as the isoscalar ones, the Dirac and Pauli form factors that correspond to the strange current are expressed as the product of an intrinsic part $g(Q^2)$ and a contribution from the vector mesons

$$\begin{aligned} F_1^s(Q^2) &= \frac{1}{2}g(Q^2) \left[\beta_\omega^s \frac{m_\omega^2}{m_\omega^2 + Q^2} + \beta_\phi^s \frac{m_\phi^2}{m_\phi^2 + Q^2} \right], \\ F_2^s(Q^2) &= \frac{1}{2}g(Q^2) \left[\alpha_\omega^s \frac{m_\omega^2}{m_\omega^2 + Q^2} + \alpha_\phi^s \frac{m_\phi^2}{m_\phi^2 + Q^2} \right]. \end{aligned} \quad (4)$$

The coefficients β and α appearing in the isoscalar and strange form factors depend on the same meson-nucleon and meson-current couplings. Following the procedure of [9], the vector meson-nucleon coupling for the ideally mixed states is parametrized as $g_i(\phi_0 N) = g_i \sin\eta_i$ and $g_i(\omega_0 N) = g_i \cos\eta_i$ for each of the two Dirac couplings ($i = 1$ for the vector coupling γ_μ and $i = 2$ for the tensor coupling $\sigma_{\mu\nu}q^\nu$), and it is assumed that the quark in the vector meson only couples to the quark current of the same flavor with a flavor-independent strength κ . As a result, the isoscalar and strange couplings depend

Table 1. Parameter values obtained in a fit to the electromagnetic form factors of the nucleon. γ is given in terms of $(\text{GeV}/c)^{-2}$. The values marked by an asterisk are obtained from (5-8).

	Ref. [5]	Present		Eq. (7)
γ	0.515	0.512		
β_ω	1.129	0.964	β_ω^s	-0.202*
α_ω	0.080*	0.088*	α_ω^s	-0.018*
β_ϕ	-0.263	-0.065*	β_ϕ^s	0.202*
α_ϕ	-0.200	-0.208	α_ϕ^s	0.648*
β_ρ	0.512	0.504		
α_ρ	2.675	2.705		

on four coefficients κg_1 , κg_2 , η_1 and η_2 . However, these couplings are constrained by the electric charges and magnetic moments of the nucleon

$$\begin{aligned}\alpha_\omega &= \mu_p + \mu_n - 1 - \alpha_\phi, \\ \beta_\omega^s &= -\beta_\phi^s,\end{aligned}\tag{5}$$

which reduces the number of independent coefficients to two only. The latter condition in (5) is a consequence of the fact that the strange (anti)quarks do not contribute to the electric charge, $G_E^s(0) = F_1^s(0) = 0$ (leading to $\eta_1 = 0$). The explicit expressions for the strange couplings are

$$\begin{aligned}\beta_\omega^s &= -\kappa g_1 \sin \epsilon \cos \epsilon, \\ \beta_\phi^s &= +\kappa g_1 \cos \epsilon \sin \epsilon, \\ \alpha_\omega^s &= -\kappa g_2 \sin \epsilon \cos(\eta_2 + \epsilon), \\ \alpha_\phi^s &= +\kappa g_2 \cos \epsilon \sin(\eta_2 + \epsilon).\end{aligned}\tag{6}$$

They are related to the isoscalar couplings by [9]

$$\begin{aligned}\beta_\omega^s/\beta_\omega &= \alpha_\omega^s/\alpha_\omega = -\sqrt{6} \sin \epsilon / \sin(\theta_0 + \epsilon), \\ \beta_\phi^s/\beta_\phi &= \alpha_\phi^s/\alpha_\phi = -\sqrt{6} \cos \epsilon / \cos(\theta_0 + \epsilon),\end{aligned}\tag{7}$$

where the angle θ_0 is defined by $\tan \theta_0 = 1/\sqrt{2}$. Equations (5) and (7) imply that the isoscalar couplings in the Dirac form factor are related to one another by

$$\beta_\phi = -\beta_\omega \tan \epsilon / \tan(\theta_0 + \epsilon).\tag{8}$$

This is in contrast with [5], where β_ω and β_ϕ were treated as independent coefficients.

4. Results

In order to calculate the nucleon form factors in the two-component model, the five remaining coefficients, γ from the intrinsic form factor, β_ω and α_ϕ from the isoscalar couplings, and β_ρ and α_ρ from the isovector couplings, are determined in a least-square

fit to the electromagnetic form factors of the proton and the neutron using the same data set as in [5]. The mixing angle ϵ can be determined either from the radiative decays of the ω and ϕ mesons [10, 11, 12] or from their strong decays [13]. The value used here is $\epsilon = 0.053$ rad [10]. The values of the five coefficients are very close to those obtained in [5], as can be seen from Table 1. Note that in [5], the sum of β_ω and β_ϕ could be determined well, but their individual values not. Table 1 shows that indeed the sum of β_ω and β_ϕ is almost the same in both cases. In the present calculation their ratio is determined by the mixing angle ϵ according to (8). The spatial extent of the intrinsic structure is found to be $\langle r^2 \rangle^{1/2} = \sqrt{12\gamma} = 0.49$ fm. The last column of Table 1 shows the values of the strange couplings as obtained from (7).

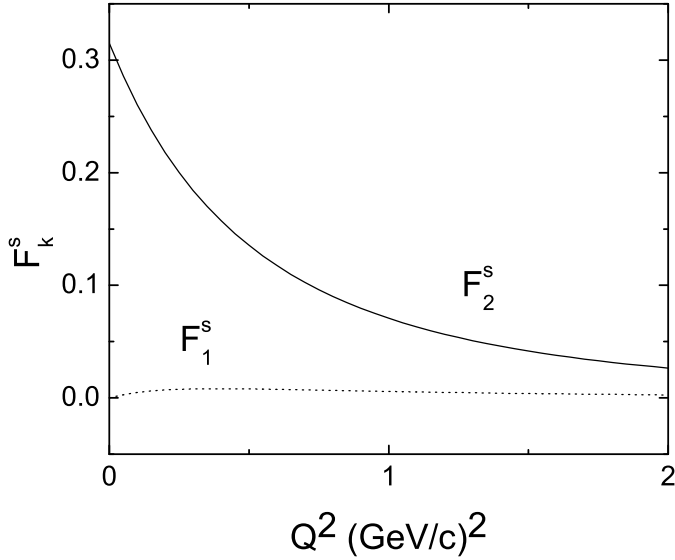


Figure 1. Strange Dirac and Pauli form factors, F_1^s (dotted line) and F_2^s (solid line).

Figure 1 shows the strange Dirac and Pauli form factors as a function of the momentum transfer Q^2 . Whereas the Pauli form factor is dominated by the coupling to the ϕ meson ($\alpha_\phi^s \gg \alpha_\omega^s$), the Dirac form factor is small due to a cancelation between the contributions from the ω and ϕ mesons ($\beta_\phi^s = -\beta_\omega^s$). The qualitative features of these form factors can be understood in the limit of ideally mixed mesons, *i.e.* zero mixing angle $\epsilon = 0$ (in comparison to the value of $\epsilon = 3.0^\circ$ used in Figure 1). Since in this case $\beta_\phi^s = \beta_\omega^s = \alpha_\omega^s = 0$, the Dirac form factor vanishes identically and the Pauli form factor depends only on the tensor coupling to the ϕ meson α_ϕ^s

$$\begin{aligned} F_1^s(Q^2) &= 0, \\ F_2^s(Q^2) &= \frac{1}{2}g(Q^2)\alpha_\phi^s \frac{m_\phi^2}{m_\phi^2 + Q^2}. \end{aligned} \quad (9)$$

The behavior of F_1^s and F_2^s in Figure 1 is quite different from that obtained in other theoretical approaches, especially for the strange Pauli form factor. Almost all calculations give negative values for F_2^s for the same range of Q^2 values [9, 14, 15, 16, 17, 18], with the exception of the meson-exchange model [19] and the $SU(3)$ chiral quark-soliton model [20]. In the former case, the values of F_2^s are about two orders of magnitude smaller than the present ones, whereas in the latter F_2^s is positive for small values of Q^2 , but changes sign around $Q^2 = 0.1 - 0.3 \text{ (GeV/c)}^2$.

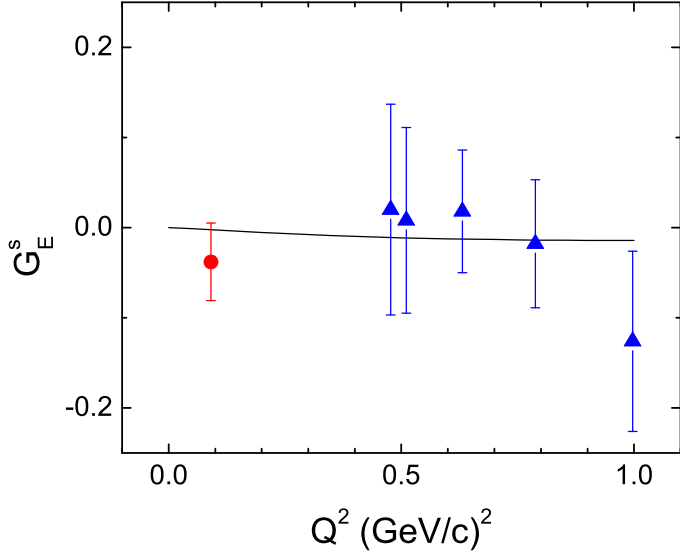


Figure 2. Comparison between theoretical and experimental values of the strange electric form factor. The experimental values are taken from [21] (circle) and [22] (triangle).

Figures 2 and 3 show the strange electric and magnetic form factors as a function of Q^2 . The theoretical values for G_E^s are small and negative, in agreement with the recent experimental result of the HAPPEX Collaboration in which G_E^s was determined in parity-violating electron scattering from ^4He [21]. The experimental value $G_E^s = -0.038 \pm 0.042 \pm 0.010$ measured at $Q^2 = 0.091 \text{ (GeV/c)}^2$ is consistent with zero. The values of G_M^s are positive, since they dominated by the contribution from the Pauli form factor. Recent experimental evidence from the SAMPLE Collaboration gives a positive value of $G_M^s = 0.37 \pm 0.20 \pm 0.07$ at $Q^2 = 0.1 \text{ (GeV/c)}^2$. The other experimental values of G_E^s and G_M^s in Figs. 2 and 3 for $0.4 < Q^2 < 1.0 \text{ (GeV/c)}^2$ were obtained [24, 22] by combining the (anti)neutrino data from E734 [25] with the parity-violating asymmetries from HAPPEX [26] and G0 [27]. The theoretical values are in good overall agreement with the experimental ones for the entire range $0 < Q^2 < 1.0 \text{ (GeV/c)}^2$.

The remaining experimental results of the strange form factors of the nucleon obtained by the PVA4, HAPPEX and G0 collaborations correspond to linear

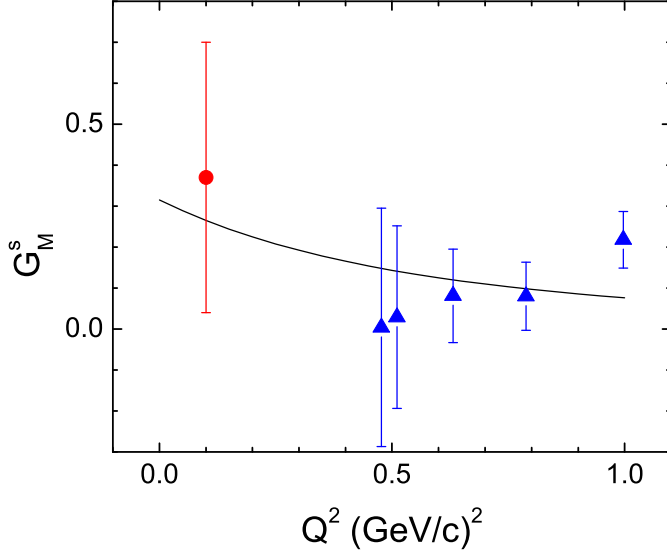


Figure 3. Comparison between theoretical and experimental values of the strange magnetic form factor. The experimental values are taken from [23] (circle) and [22] (triangle).

Table 2. Comparison between theoretical and experimental values of strange form factors $G_E^s + \eta G_M^s$.

Q^2 (GeV/c) ²	η	$G_E^s + \eta G_M^s$		
		Present	Experiment	Reference
0.099	0.080	0.019	0.030 ± 0.028	[2]
0.108	0.106	0.025	0.071 ± 0.036	[28]
0.230	0.225	0.042	0.039 ± 0.034	[29]
0.477	0.392	0.047	0.014 ± 0.022	[26]

combinations of electric and magnetic form factors $G_E^s + \eta G_M^s$. Table 2 and Figure 4 show a good agreement between the results from the present calculations and the experimental data.

In the majority of theoretical analyses, the strangeness contribution to the nucleon is discussed in terms of the static properties, the strange magnetic moment μ_s and the strangeness radius $\langle r_s^2 \rangle$. Figure 5 shows a compilation of theoretical values of these two quantities (filled circles). Most studies agree on a small negative strangeness radius and a moderate negative strange magnetic moment [3], whereas the results of a combined fit of the strange electric and magnetic form factors measured by SAMPLE, PVA4 and HAPPEX at $Q^2 \sim 0.1$ (GeV/c)², $G_M^s(0.1) = 0.55 \pm 0.28$ and $G_E^s(0.1) = -0.01 \pm 0.03$ [2], indicate the opposite sign for both μ_s and $\langle r_s^2 \rangle$. Recent lattice calculations give a

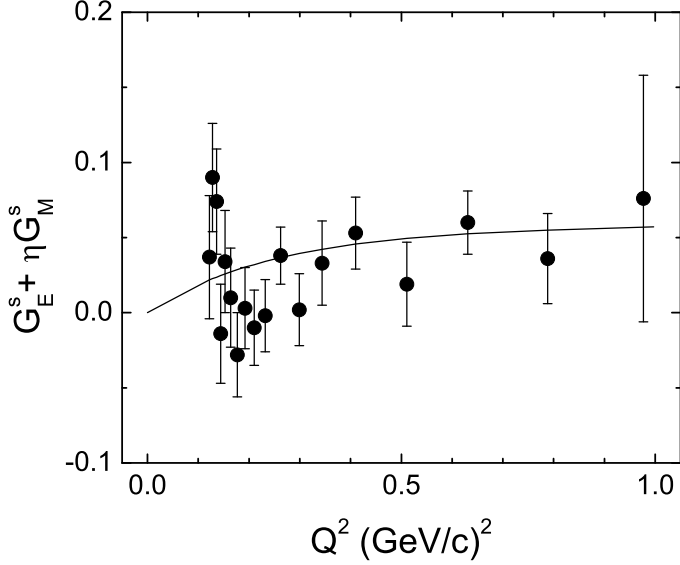


Figure 4. Comparison between theoretical and experimental values of strange form factors $G_E^s + \eta G_M^s$. The experimental values were measured by the G0 Collaboration [27].

slightly negative values of the strange magnetic moment $\mu_s = -0.046 \pm 0.019 \mu_N$ [30] and the strange electric form factor $G_E^s(0.1) = -0.009 \pm 0.028$ [31].

In the present approach, the strange magnetic moment is given by

$$\mu_s = G_M^s(0) = \frac{1}{2}(\alpha_\omega^s + \alpha_\phi^s) = 0.315 \mu_N. \quad (10)$$

μ_s does not depend on the mixing angle ϵ , since according to (6) one has $\alpha_\omega^s + \alpha_\phi^s = \kappa g_2 \sin \eta_2$. Its sign is determined by the sign of the tensor coupling α_ϕ^s ($\gg \alpha_\omega^s$, see Table 1). The strangeness charge radius is given by

$$\begin{aligned} \langle r_s^2 \rangle_E &= -6 \left. \frac{dG_E^s(Q^2)}{dQ^2} \right|_{Q^2=0} \\ &= 3\beta_\phi^s \left(\frac{1}{m_\phi^2} - \frac{1}{m_\omega^2} \right) + \frac{3}{4M_N^2}(\alpha_\omega^s + \alpha_\phi^s) = 0.005 \text{ fm}^2. \end{aligned} \quad (11)$$

The first term is entirely due to the VMD contribution. In the absence of mixing, $\beta_\phi^s = 0$ and the strangeness radius depends on the second term only $\langle r_s^2 \rangle_E = 3\mu_s/2M_N^2 = 0.021 \text{ fm}^2$. Similarly, the strangeness magnetic radius is given by

$$\begin{aligned} \langle r_s^2 \rangle_M &= -\frac{6}{\mu_s} \left. \frac{dG_M^s(Q^2)}{dQ^2} \right|_{Q^2=0} \\ &= 6 \left[2\gamma + \frac{\beta_\phi^s + \alpha_\phi^s}{\alpha_\omega^s + \alpha_\phi^s} \frac{1}{m_\phi^2} + \frac{\beta_\omega^s + \alpha_\omega^s}{\alpha_\omega^s + \alpha_\phi^s} \frac{1}{m_\omega^2} \right] = 0.410 \text{ fm}^2. \end{aligned} \quad (12)$$

The first term is due to the intrinsic form factor, whereas the last two terms arise from

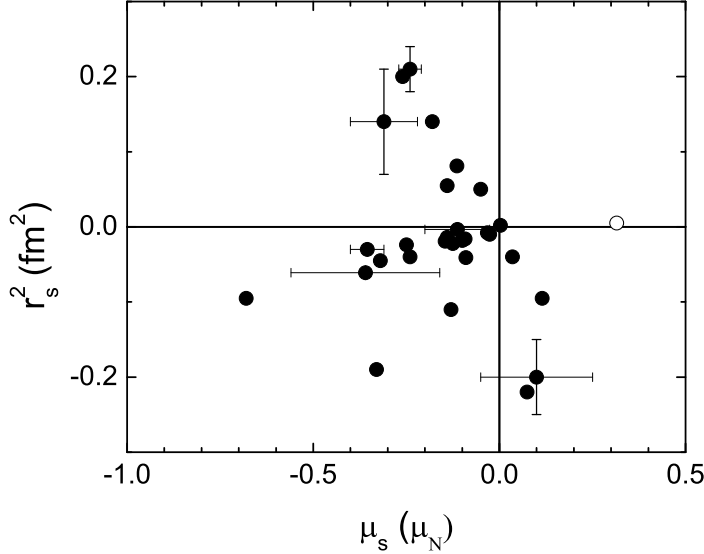


Figure 5. Theoretical values of the strange magnetic moments and the strangeness radii (filled circles) [3]. The present value is denoted by an open circle.

the VMD contribution. In the absence of mixing, $\beta_\phi^s = \beta_\omega^s = \alpha_\omega^s = 0$ and the strangeness magnetic radius of (12) reduces to two terms only which contribute almost the same amount to the radius $\langle r_s^2 \rangle_M = 6[2\gamma + 1/m_\phi^2] = 0.403 \text{ fm}^2$.

The values of the strangeness contribution to the magnetic moment and the charge radius in the two-component model are indicated in Figure 5 by an open circle. The signs of both quantities are found to be positive, in agreement with the available experimental evidence. A positive value of the strange magnetic moment seems to preclude an interpretation in terms of a $uuds\bar{s}$ fluctuation into a ΛK configuration [32]. On the other hand, an analysis of the magnetic moment of $uuds\bar{s}$ pentaquark configurations belonging to the antidecuplet gives a positive strangeness contribution for states with angular momentum and parity $J^P = 1/2^+, 1/2^-$, and negative for $3/2^+$ states [33].

5. Summary and conclusions

In summary, in this Letter it was shown that the recent experimental data on the strange nucleon form factor can be explained very well in a two-component model of the nucleon consisting of an intrinsic three-quark structure with a spatial extent of $\sim 0.49 \text{ fm}$ surrounded by a meson cloud. The present approach is a combination of the two-component model of Bijker and Iachello for the electromagnetic nucleon form factors [5] and a mechanism to determine the strangeness content via the coupling of the strange current to the ϕ and ω mesons according to Jaffe [9]. The condition that the strange

quarks do not contribute to the electric charge of the nucleon, reduces the number of independent coefficients of the two-component model of [5] by one. The parameters are completely determined by the electromagnetic form factors of the proton and neutron.

The good overall agreement between the theoretical and experimental values for the electromagnetic form factors of the proton and neutron and their strange quark content shows that the two-component model provides a simultaneous and consistent description of the electromagnetic and weak vector form factors of the nucleon. In particular, the strange magnetic moment was found to be positive, in contrast with most theoretical studies, but in agreement with the results from parity-violating electron scattering experiments.

The first results from the SAMPLE, PVA4, HAPPEX and G0 collaborations have shown evidence for a nonvanishing strange quark contribution to the charge and magnetization distributions of the nucleon. Future experiments on parity-violating electron scattering and neutrino scattering hold great promise to make it possible to unravel the contributions of the different quark flavours to the electric, magnetic and axial form factors, and thus to give new insight into the complex internal structure of the nucleon.

Acknowledgments

This work was supported in part by a grant from CONACYT, Mexico. It is a pleasure to thank Franco Iachello for interesting discussions.

References

- [1] Kaplan D B and Manohar A 1988 *Nucl. Phys. B* **310** 527
McKeown R D 1989 *Phys. Lett. B* **219** 140
Beck D H 1989 *Phys. Rev. D* **39** 3248
- [2] Aniol K A *et al.* 2006 *Phys. Lett. B* **635** 275
- [3] Beck D H and Holstein B R 2001 *Int. J. Mod. Phys. E* **10** 1
Beck D H and McKeown R D 2001 *Annu. Rev. Nucl. Part. Sci.* **51** 189
- [4] Iachello F, Jackson A D and Lande A 1973 *Phys. Lett. B* **43** 191
- [5] Bijker R and Iachello F 2004 *Phys. Rev. C* **69** 068201
- [6] Frank M R, Jennings B K and Miller G A 1996 *Phys. Rev. C* **54** 920
Pace E, Salmè G, Cardarelli F and Simula S 2000 *Nucl. Phys. A* **666** 33c
- [7] Bijker R, Iachello F and Leviatan A 1994 *Ann. Phys. (N.Y.)* **236** 69
Bijker R, Iachello F and Leviatan A 1996 *Phys. Rev. C* **54** 1935
- [8] Lepage G P and Brodsky S J 1979 *Phys. Rev. Lett.* **43** 545
Lepage G P and Brodsky S J 1980 *Phys. Rev. D* **22** 2157
- [9] Jaffe R L 1989 *Phys. Lett. B* **229** 275
- [10] Jain P, Johnson R, Meissner U.-G, Park N W and Schechter J 1988 *Phys. Rev. D* **37** 3252
- [11] Iachello F and Kusnezov D 1992 *Phys. Rev. D* **45** 4156
- [12] Harada M and Schechter J 1996 *Phys. Rev. D* **54** 3394
- [13] Gobbi C, Iachello F and Kusnezov D 1994 *Phys. Rev. D* **50** 2048
- [14] Park N W and Weigel H 1992 *Nucl. Phys. A* **541** 453
- [15] Garvey G T, Louis W C and White D H 1993 *Phys. Rev. C* **48** 761

- [16] Forkel H, Nielsen M, Jin X and Cohen T D 1994 *Phys. Rev. C* **50** 3108
- [17] Hammer H.-W, Meissner U.-G and Drechsel D 1996 *Phys. Lett. B* **367** 323
- [18] Lyubovitskij V E, Wang P, Gutsche Th and Faessler A 2002 *Phys. Rev. C* **66** 055204
- [19] Meissner U.-G, Mull V, Speth J and Van Orden J W 1997 *Phys. Lett. B* **408** 381
- [20] Silva A, Kim H.-Ch and Goeke K 2004 *Eur. Phys. J. A* **22** 481
- [21] Aniol K A *et al.* 2006 *Phys. Rev. Lett.* **96** 022003
- [22] Pate S F, MacLachlan G, McKee D and Papavassiliou V Strangeness contribution to the vector and axial form factors of the nucleon *Preprint* hep-ex/0512032
- [23] Spayde D T *et al.* 2004 *Phys. Lett. B* **583** 79
- [24] Pate S F 2004 *Phys. Rev. Lett.* **92** 082002
- [25] Ahrens L A *et al.* 1987 *Phys. Rev. D* **35** 785
- [26] Aniol K A *et al.* 2004 *Phys. Rev. C* **69** 065501
- [27] Armstrong D S *et al.* 2005 *Phys. Rev. Lett.* **95** 092001
- [28] Maas F E *et al.* 2005 *Phys. Rev. Lett.* **94** 152001
- [29] Maas F E *et al.* 2004 *Phys. Rev. Lett.* **93** 022002
- [30] Leinweber D B, Boinepalli S, Cloet I C, Thomas A W, Willams A G, Young R D, Zanoliti J M and Zhang J B 2005 *Phys. Rev. Lett.* **94** 212001
- [31] Leinweber D B, Boinepalli S, Thomas A W, Wang P, Willams A G, Young R D, Zanoliti J M and Zhang J B Strange electric form factor of the proton *Preprint* hep-lat/0601025
- [32] Zou B S and Riska D O, 2005 *Phys. Rev. Lett.* **95** 072001
- [33] Bijker R, Giannini M M and Santopinto E 2004 *Phys. Lett. B* **595** 260